NORTEL

White Paper

Mobile Backhaul Evolves with Carrier Ethernet

Introduction

Although in some countries mobile phone penetration has passed 100%, the total number of mobile subscribers worldwide at the end of 2005 was 2.13 billion and is predicted to reach 3.96 billion by 2011[1]. However, it's not just an increase in the subscribers that wireless operators have to cope with: the increased availability of mobile data devices such as 3G handsets, laptop cards and personal digital assistants (PDAs) has driven demand for new mobile data, video and multimedia services. These services are made possible by 3G technologies like High-Speed Downlink Packet Access (HSDPA) that can support downlink speeds of up to 14.4 Mbps. This demand for mobile data services is further accelerated by 4G technologies – like WiMAX (Worldwide interoperability for Microwave Access), UMB (Ultra Mobile Broadband) and LTE (Long Term Evolution) – that are now beginning to be deployed. The challenge wireless operators face is to support more subscribers and satisfy higher bandwidth requirements per subscriber.

As a result, wireless operators must reassess their current backhaul infrastructure. For current 2G networks the typical model has been to use PDH, SONET/SDH leased lines or microwave to carry TDM voice traffic from base transceiver stations (BTS) to base station controllers (BSC). Similarly, 3G networks use leased lines to provide ATM backhaul between the UMTS Node B (BTS equivalent) and the Radio Network Controller (RNC). Leased-line OPEX is already the single largest area of spending for wireless operators – estimated at $22 billion per year globally[2] – and the huge increase in traffic created by mobile data services makes this model unsustainable. Increasingly, in an attempt to capture some of the lucrative broadband market for fixed mobile convergence, wireless operators are turning to Carrier Ethernet to help control OPEX and provide a more flexible shared bandwidth access infrastructure. For years, Ethernet has dominated the LAN and now, with the addition of a number of key technology enablers, Ethernet is capable of carrier-grade performance and is referred to as Metro or Carrier Ethernet. The widespread adoption of Ethernet has made it more cost-effective than any other networking technology. With Gigabit Ethernet and 10 Gigabit Ethernet now readily available (with higher speeds under development), Ethernet offers wireless operators both the bandwidth and cost points needed to support mobile multimedia services.

The rest of this paper looks at some of the technologies for ensuring Carrier Ethernet meets the key performance indicators required by mobile backhaul applications and discusses how the current backhaul infrastructure is expected to evolve.

[1] *Worldwide Mobile Market Forecasts 2006 – 2011 Portio Research, January 2006*

[2] *Yankee Group*

Key performance indicators

Although the potential benefits of Carrier Ethernet are understood, mobile backhaul infrastructures are also subject to a number of key performance indicators (KPIs) and Carrier Ethernet must also meet these:

- **Delay** – mobile backhaul is part of the overall Radio Access Network (RAN), which has a tightly controlled delay budget. This ensures that voice services meet quality criteria for ease of conversation and assures the response time of mobile data services and RAN control protocols. Since the delay budget of the whole RAN is in the order of 100 milliseconds, the delay of the backhaul segment between the BTS and BSC must be kept as low as 3–5 milliseconds for some applications.
- **Loss Rate** – this value depends on the manner of the supported service. Where the existing PDH/SDH leased-line infrastructure is to be emulated, the target effective random bit-error ratio (ERBER) would be 1×10^{-7} end-to-end or per-segment, which is similar to the in-service criteria for a transport network. In an evolved 3G Node B where voice and data services may be transported directly over IP and Ethernet, the loss criteria drops to 10^{-5} and 10^{-4} respectively for acceptable throughput and performance.
- **Synchronisation** – in order to ensure licensed radio frequency accuracy and that inter-cell handoffs are manageable by the widest range of affordable handsets, every BTS in a 2G network (or Node B in a 3G network) must be able to trace frequency synchronisation back to a primary reference clock (PRC) source in normal operation. Failure to do this can result in a mobile device losing 'lock', which can adversely affect voice and data services or result in dropped calls. The required performance is based on a relative degradation of the PRC by existing transport systems; the standards for E1/T1 jitter and wander impairments are those defined in ITU-T G.823/G.824/G.825 for traffic interfaces and SONET/SDH transport. Adhering to the standards avoids the need to perform any significant upgrade of existing mobile infrastructure.
- **Availability** – mobile backhaul networks have been designed and built on an assumption that the transport network will meet a 'four-nines' or 'five-nines' network availability target. This requires a range of protection mechanisms capable of sub-50 millisecond recovery when outages occur and the mean-time-to-repair (MTTR) target is typically two to three hours.

Enabling technologies

As previously mentioned, a number of Ethernet innovations have emerged to ensure that Carrier Ethernet provides carrier-grade packet transport and meets the performance criteria for mobile backhaul applications.

Provider Backbone Transport (PBT)

PBT (IEEE 802.1Qay PBB-TE) delivers the carrier-grade connection management characteristics of SONET/SDH, over an otherwise connectionless Ethernet network. It achieves this by disabling MAC learning and instead populating the Ethernet forwarding tables via the provisioning system, allowing operators to specify the path that an Ethernet frame should take across the network. The result is totally predictable behaviour under all network conditions, delivering the Quality of Service (QoS) required to meet the operator's KPI targets (e.g. less than 3–5 milliseconds delay).

Existing Quality of Service (QoS) mechanisms (e.g. IEEE 802.1p) can be applied to allow delay-sensitive traffic such as voice and video to be prioritised above best-effort sources (such as email and web browsing). When QoS mechanisms are combined with Connection Admission Control (CAC), the network can protect high priority applications by determining availability of network resources to support a new connection over the network before accepting a new load. This ensures negligible frame loss by avoiding network congestion, and the network can be operated so that the load on any link and any node is below a targeted sweet spot under all conditions.

In addition to the QoS benefits, PBT allows for higher backhaul reliability through the creation of optional redundant Ethernet tunnels. The latest developments in Ethernet OAM (IEEE 802.1ag Connectivity Fault Management) allow for 'keep alive' or Connectivity Check Messages to be exchanged between the two ends of a trunk. Failure to receive three consecutive messages results in a fault being detected against the trunk and a protection switch is initiated. The development of ITU-T G.8031 (Ethernet Linear Protection) means that sub-50 millisecond protection switching can now be achieved.

PBT was subject to an IEEE Project Authorization Request (PAR) in late 2006, which has now been approved, and a PBT standard, IEEE 802.1Qay (Provider Backbone Bridge – Traffic Engineering) is now under development.

Figure 1: PBT Trunks

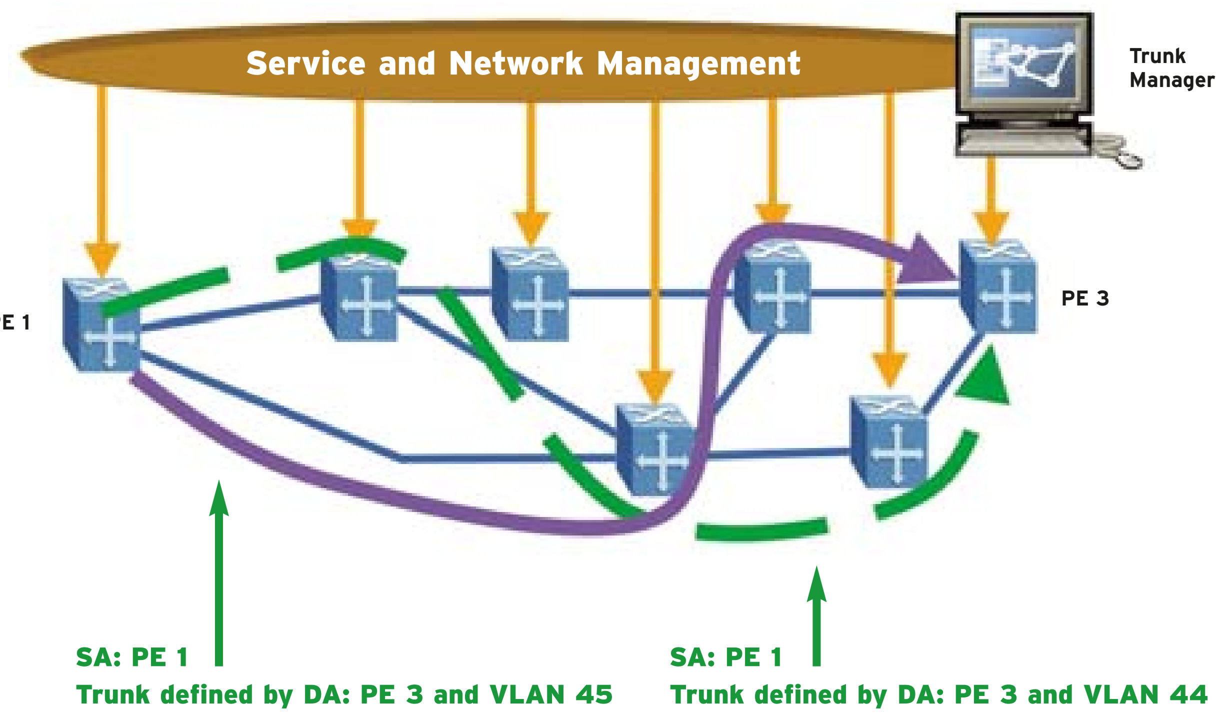
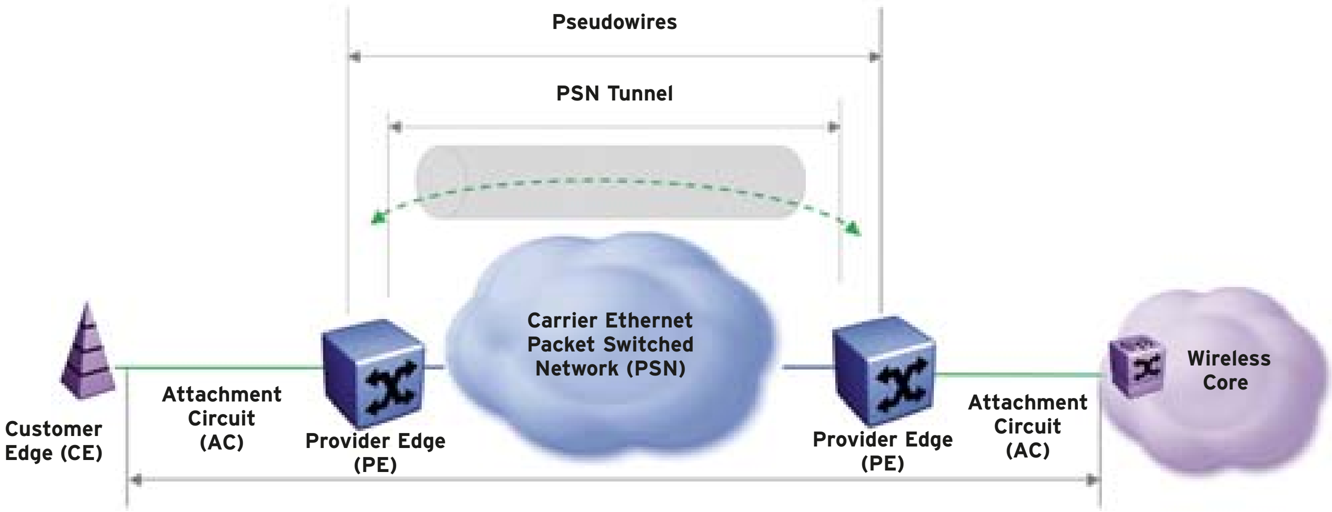


Figure 2: Pseudowire Connectivity to the Base Station



Pseudowires

While PBT provides an option for carrier-grade Ethernet connectivity to support the next generation of 3G and 4G base stations, it is important to realise that existing base stations and Node Bs will continue to require ATM and TDM connectivity. Fortunately, this requirement is not restricted to just mobile backhaul and has already been tackled by pseudowire technology, which has emerged as a method of providing existing WAN services over a packet-based infrastructure. Pseudowires are defined by the Internet Engineering Task Force (IETF) Pseudowire Emulation Edgeto- Edge (PWE3) group and their use in mobile backhaul networks is illustrated in Figure 2.

In this example, the CE device is a base station or Node B requiring TDM or ATM connectivity respectively. This requirement is supported by an Attachment Circuit (AC) that is encapsulated in a pseudowire at the PE device and carried across a connection-oriented tunnel over the PSN. Different pseudowire encapsulations exist to support ATM and TDM services and initial implementations have been based on IP/MPLS networks where label switched paths (LSPs) provide the tunnelling mechanism over the PSN. However, it is equally valid for a Carrier Ethernet network to assume the role of the PSN and a PBT tunnel to provide the connectivity for the pseudowire. This method is described in IETF draft-allan-pw-o-pbt-00 (Pseudo Wires over Provider Backbone Transport).

Synchronisation

As previously discussed, it's vital that all network elements in a wireless network are traceable to a PRC source. This is particularly critical for GSM and WCDMA base stations that derive their clock frequency from the core network and do not rely on global positioning system (GPS)-based mechanisms for synchronisation. In existing 2G/3G networks, base stations can derive synchronisation from the SONET/SDH leased lines that backhaul the traffic. When SONET/SDH backhaul is replaced by Carrier Ethernet technologies, Ethernet transport must be able to provide the connectivity to a synchronisation source. However, like other packet-based technologies, Ethernet is an asynchronous transport technology and does not currently provide any such services on its own. Various standards bodies have been looking into this issue and the International Telecommunication Union (ITU-T) released a new recommendation in April 2006, ITU-T G.8261 (Timing and Synchronization Aspects in Packet Networks), leading to two different solutions emerging which are based on either Layer 1 (physical) or Layer 2 (packet) methodologies.

The first approach distributes timing at Layer 1 (the physical layer). This approach requires embedding a clock distribution signal in the line code, similar to the method of synchronisation used today in SONET/SDH networks and thus often referred to as 'Synchronous Ethernet'. This technique can be used for all Ethernet port rates above 100 Mbps and testing has shown that it is extremely accurate for transporting a clock signal using existing PHY devices. However, this approach requires a hardware upgrade to Ethernet switch backplanes, port cards and switch fabrics and because fibre often does not reach BTS installations and is expensive, a variety of cheaper access technologies such as DSL, cable, PON and microwave are under consideration. These technologies have their own physical layer clock and it is not yet possible for Synchronous Ethernet to interwork with each. Consequently, there is a need for a synchronisation mechanism that can tunnel through all of these as a means of providing service consistency.

The second approach distributes timing at Layer 2 (packet) using timestamps embedded within an Ethernet frame or IP packet. The base station or a closely positioned proxy can then recover the timestamp from the Ethernet frame or packet, and regenerate the original frequency to a given accuracy using sophisticated algorithms. This approach means that the synchronisation is not dependent in any way on the actual physical layer and so works transparently with the many different access transport layers mobile operators are considering. However, unlike physical layer timing distribution, this technique is vulnerable to packet network impairments such as jitter, end-to-end delay and, to a lesser degree, frame loss or misordering, which unless bounded by a deterministic packet layer can result in considerably poorer performance than Synchronous Ethernet can achieve. Performance also varies among the several Layer 2 techniques available: Adaptive Clock Recovery (ACR) algorithm is a one-way algorithm that is adequate for frequency distribution; Precision Timing Protocol (PTP) is a two-way algorithm defined by IEEE 1588 (Precision Clock Synchronization Protocol for Networked Measurement and Control Systems), which can be used for frequency phase and time distribution. Tests conducted in Nortel laboratories have shown that satisfactory results for mobile backhaul frequency synchronisation can be achieved by using either of the state-of-the-art Layer 2 techniques over a PBT-enabled Carrier Ethernet network, since PBT provides a guaranteed bandwidth of deterministic performance and ensures that the effects of packet network impairments are minimal.

Provider Link State Bridging (PLSB)

As discussed, emerging 4G technologies like LTE support new multimedia applications by introducing higher bandwidths. As well as greatly increasing mobile backhaul traffic demands, the LTE architecture introduces a change in traffic patterns. This is because LTE uses a flatter architecture with fewer specialised nodes than existing 2G and 3G networks. In LTE, the Enhanced Node B (eNB) is capable of features normally associated with centralised nodes, such as dynamic allocation of resources to users, radio resource management and IP compression. As a consequence of this additional functionality at the eNB, LTE introduces the requirement for direct connectivity between base stations. This differs from the 2G/3G mobile backhaul requirement where traffic connectivity is only required between the BTS and BSC controller, and as a result, creates a requirement for E-LAN (multipoint-to-multipoint) services in the 4G RAN.

The emergence of Provider Link State Bridging (PLSB) introduces a solution for carrier-grade E-LAN and E-TREE (point-to-multipoint) services with fast restoration and guaranteed performance levels. Standard Ethernet has always been capable of supporting the full range of connectivity modes, but its reliance on Spanning Tree Protocol (STP) has restricted Ethernet to LANs. The first technology to address this limitation was PBT, which disabled STP and configured the Ethernet data plane through the management or control plane. However, PBT is primarily for point-to-point connections and an alternative solution is needed to offer carrier-grade E-LAN services.

PLSB achieves this by disabling STP and using IS-IS (Intermediate System to Intermediate System) to learn the network topology and configure Ethernet services across the network. As a result, PLSB delivers the following benefits that can be applied to 4G/LTE backhaul:

- **Improved resiliency** – STP can take several seconds to re-converge under failure conditions. In comparison, PLSB with IS-IS can dynamically calculate and install an alternative route in 100s of milliseconds.
- **Better network utilisation** – STP calculates and installs a single spanning tree for the entire network. This means links not used are blocked resulting in wasted capacity. Furthermore, traffic always follows the path enforced by the spanning tree even if a shorter path exists. PLSB uses IS-IS to calculate and install a shortest path tree for every node in the network, so that every link in the network is utilised and traffic always follows the shortest path.
- **Autodiscovery** – PLSB uses IS-IS to distribute B-MAC (Backbone MAC address) and I-SID (Service ID) information between neighbouring nodes. Each node repeats this process until every node in the network shares a common view of the topology. As a consequence, new nodes are automatically discovered when they are added to the network.

This last point makes PLSB ideal for the Self-Optimizing Network (SON) requirements currently under review by the Next Generation Mobile Networks (NGMN) alliance. By enabling single-touch provisioning, PLSB allows dynamic re-configuration of the network as traffic connectivity changes and new nodes are added. This provides the flexibility and functionality required by the SON architecture.

The ideas and concepts introduced by PLSB are included in the latest draft of IEEE 802.1aq (Shortest Path Bridging).

Network evolution

In the final part of this paper we look at how mobile backhaul networks are likely to evolve as traffic loads increase and become more packet-based. As discussed previously, today's 2G/3G networks use PDH leased lines to provide backhaul capacity between the BTS and BSC (as shown in Figure 3). In the case of 2G networks, the leased lines support TDM traffic, while in WCDMA 3G networks ATM backhaul is supported using Inverse Multiplexing for ATM (IMA). Wireless operators can build this infrastructure on their own, but a more likely scenario is that they purchase the cell site and aggregation equipment and lease the interconnect capacity from a wireline service provider.

The demand for data services is placing increased strain on the existing mobile backhaul infrastructure, to the extent that services cannot be deployed unless the backhaul is upgraded. However, instead of migrating directly to a Carrier Ethernet network, many wireless operators are sweating their existing TDM and ATM based assets and simply considering adding a low cost Ethernet access service. Figure 4 shows how high-bandwidth data applications can be offloaded at the BTS sites onto an Ethernet connection while delay-sensitive voice traffic continues to be carried over the existing leased lines.

While this approach helps ease the strain induced by data service demand, the only way to eliminate the existing OPEX of the mobile backhaul is to realise the full economic and scalability opportunities of Ethernet. Mobile operators are testing the water with MPLS as an aggregating transport technology, but it can be shown that a Carrier Ethernet infrastructure offers the lowest cost solution for all backhaul. This solution is shown in Figure 5. At this stage, a predictable and QoS-assured Carrier Ethernet backhaul using PBT technology provides a complete backhaul for all mobile voice and data traffic, including legacy 2G voice services. In this example a pseudowire multiplexer is deployed at the cell site, allowing ATM and TDM access to be provided to existing 2G/3G base stations over a packet-based network. To support the need for timing distribution, a Layer 2 synchronous transport mechanism is also implemented in the pseudowire multiplexer in this example. The resulting network provides a common infrastructure for existing 2G/3G networks and is ready for the increased bandwidth required by emerging 4G technologies, which support native Ethernet interfaces. Should the mobile operator migrate to an LTE architecture, it is possible to support PLSB on the same Carrier Ethernet infrastructure by implementing PLSB and PBT on separate VLANs. This allows the operator to meet the requirement for carrier-grade E-LINE and E-LAN services.

Figure 3: Present Mode of Operation

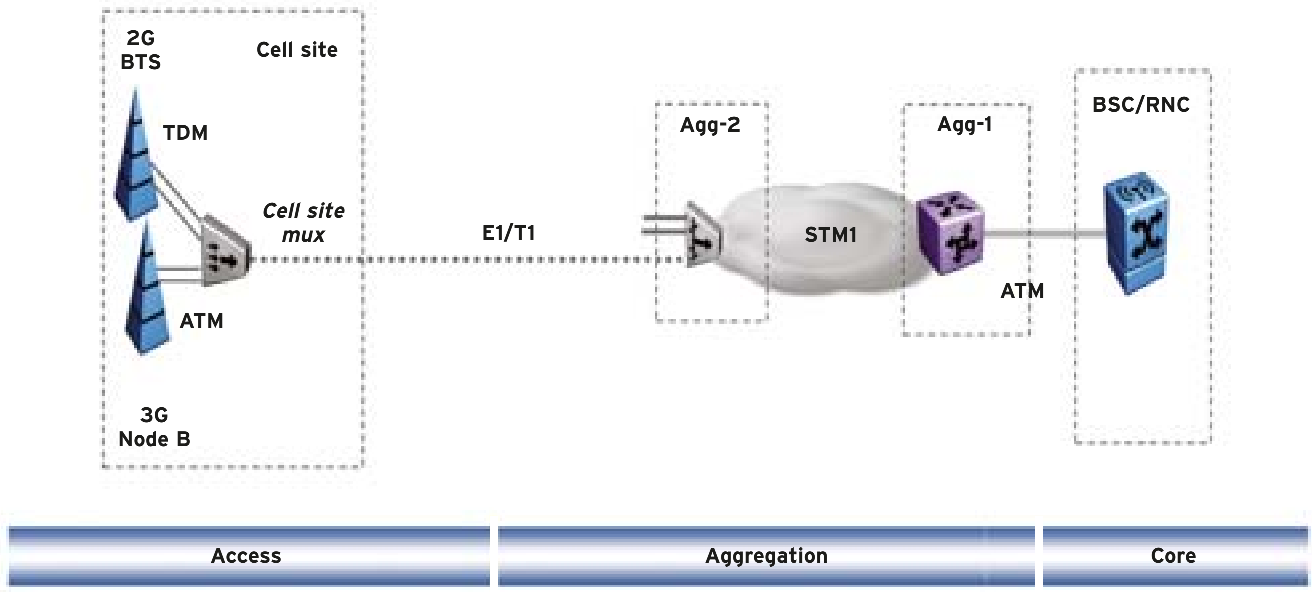
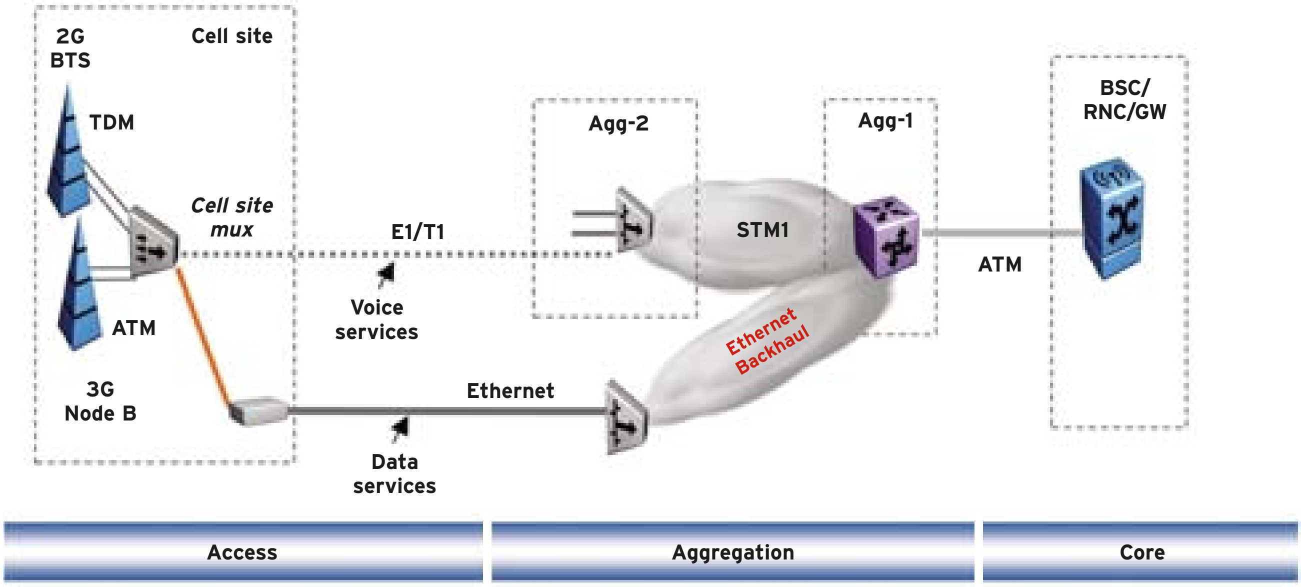


Figure 4: HSDPA Offload

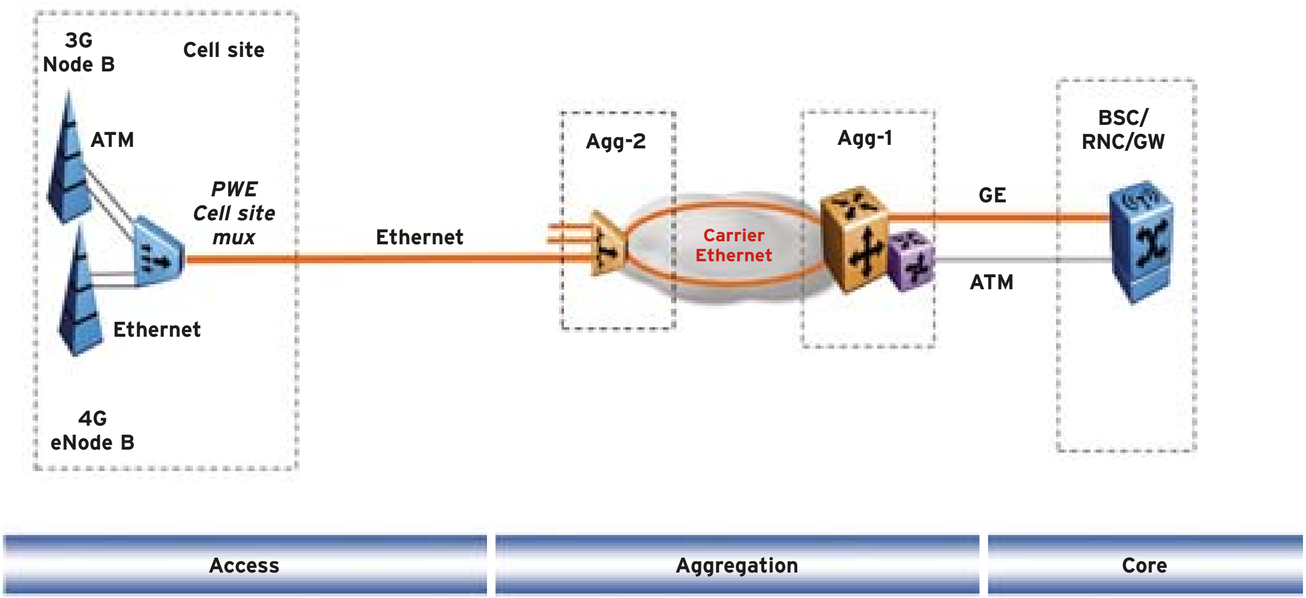


Summary

Wireless traffic volume is growing at a staggering pace, driven by new high-speed mobile services such as mobile video, multimedia messaging and web browsing. This traffic growth is made possible by new 3G deployments such as CDMA EV-DO and UMTS HSDPA, and with 4G technologies like WiMAX, UMB and LTE on the horizon this trend is set to continue. To cope with the additional traffic generated, operators will need to invest in new transport capacity to the base stations. Since it is not cost effective simply to grow the existing E1/T1 connections, connectivity for mobile backhaul will migrate towards native packet transport technologies and Carrier Ethernet in particular, which provides the bandwidth flexibility and price points required.

For any packet technology to succeed as a valid transport option for mobile backhaul it must meet the key performance indicators of delay, loss, availability and synchronisation. A PBT-enabled Carrier Ethernet network provides the guaranteed, deterministic performance of SONET/SDH over a cost-effective packet-based network. Pseudowires can be used to provide existing ATM and TDM services to legacy base station and Node Bs as required, while the emergence of Layer 1 and 2 synchronisation ensures that an accurate and consistent timing source can be provided to cell sites over a Carrier Ethernet network. Finally, the LTE architecture requires E-LAN connectivity between base stations (enhanced Node Bs or eNBs) and the emerging PLSB standard provides a carrier grade solution for E-LAN services to complement the existing E-LINE capabilities.

Figure 5: Carrier Ethernet Access and Backhaul



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